Draft Final Report
Design Procedure Literature Review

DESIGN & MAINTENANCE OF DEEP-DRAFT NAVIGATION CHANNELS

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AN OVERVIEW OF CURRENT PRACTICE WITH AN ANNOTATED BIBLIOGRAPHY

A Document Prepared In Fulfillment of Milestone Number 2
of the U.S. Army Corps of Engineers' R&D Work Unit Entitled

Impacts of Navigation Trends on Channel Usage and Design

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ABSTRACT

Among the vital missions of the U.S. Army Corps of Engineers (Corps) is the development and maintenance of inland and coastal waterways in support of commercial navigation. Currently, the Corps is responsible for maintaining and improving more than 200 deep-draft ports and harbors. In fulfillment of this responsibility, the Corps' Institute for Water Resources (IWR) has initiated a study entitled "Impacts of Navigation Trends on Channel Usage and Design." Its principal goal is to improve the design and maintenance of navigation channels in order to sustain effective channel navigation and port operations well into the next century.

As part of this study, a literature review was conducted and an annotated bibliography developed. The principal focus of the bibliography was current practices used domestically and internationally to design and maintain deep-draft navigation channels. However, related issues of navigational safety in coastal waterways and shipping trends were also included within the scope of the literature search. The bibliography, containing over 200 literature references and nearly 30 relevant web-site addresses, was prepared in an electronic database for future reference. Bibliographic information contained in the database is reproduced in the Appendix.

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ACKNOWLEDGMENTS

The authors wish to acknowledge the assistance of ENS Steve Beede, U.S.N., and Ms. Jacqueline Schultz of Webb Institute. ENS Beede initiated compilation of the database and helped us during the early phases of document identification, location and assessment. Ms. Schultz prepared many of the text figures and helped in maintaining and updating the bibliography. Mrs. Mary Jane Robertson, Administrative Officer for the U.S. Section of PIANC, located and provided us access to many international documents on channel design and maintenance. Her assistance is also greatly appreciated.

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ACRONYMS

AAPA	...	American Association of Port Authorities
ASCE	...	American Society of Civil Engineers
CETN	...	Coastal Engineering Technical Note
CHL	...	Coastal and Hydraulics Laboratory
DNV	...	Det Norte Veritas
EM	...	Engineer Manual
EP	...	Engineer Pamphlet
ER	...	Engineer Regulation
ETL	...	Engineer Technical Letter
IAPH	...	International Association of Ports and Harbors
IWR	...	Institute for Water Resources
MARAD	...	U.S. Maritime Administration
MIL-HDBK	...	Military Handbook
NAP	...	National Academy Press
NAVFAC	...	Naval Facilities Engineering Command
NDC	...	Navigation Data Center
NFESC	...	Naval Facilities Engineering Service Center
NRC	...	National Research Council
PIANC	...	Permanent International Association of Navigation Congresses
USACE	...	U.S. Army Corps of Engineers
USCG	...	U.S. Coast Guard
WES	...	U.S. Army Engineer Waterways Experiment Station

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Design & Maintenance of
Deep-Draft Navigation Channels

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An Overview of Current Practices
with an Annotated Bibliography

Part I. INTRODUCTION

Background

Among the vital missions of the U.S. Army Corps of Engineers (Corps) is the development and maintenance of inland and coastal waterways in support of commercial navigation. Currently, the Corps is responsible for maintaining and improving more than 200 deep-draft ports and harbors which, for purposes of this report, are defined as those with authorized channel depths greater than 15 feet. These facilities are vital to the health of the nation's economy. They handle nearly all of U.S. foreign trade which, annually, involves millions of tons of grain and coal exports, petroleum imports, and imports and exports of general merchandise [1].

Prevailing economic factors compel the shipping industry to develop ships - tankers, freighters and containerships - of increasing size and speed to carry this cargo. This trend necessitates that U.S. ports adapt to accommodate these vessels so as to maintain U.S. competitiveness in the international shipping industry. Such adaptations will affect how deep-draft navigation channels are designed and maintained.

Existing Corps Regulations and Design Guidance

There are two principal Corps documents that provide explicit design and policy guidance for deep-draft navigation channels. These are the Engineer Regulation (ER) 1110-2-1404, "Hydraulic Design of Deep-Draft Navigation Projects," dated 31 January 1996; and, the Engineer Manual (EM) 1110-2-1613, "Hydraulic Design Guidance for Deep-Draft Navigation Projects," dated 31 August 1995.

The regulation provides a brief overview of the design process and report requirements for Corps deep-draft navigation projects. It also establishes the criteria - safety, efficiency, reliability and economy - by which such projects must be justified. The companion manual details procedures for preliminary design analysis and provides guidance for the layout and design of deep-draft navigation channels. While this guidance reflects the experience of the many Corps personnel involved in deep-draft navigation studies and projects, the design engineer is advised to adapt the manual's general guidance to site-specific conditions.

These and other documents on deep-draft navigation channel design and maintenance are identified and characterized in the bibliography that appears in the Appendix. The bibliography database from which the Appendix was compiled is discussed in Part III of this report.

Aim of the Report

Given the increasing size and speed of ships in the world fleet and related changes in port and channel usage, the Corps' Institute for Water Resources (IWR) has initiated a study entitled "Impacts of Navigation Trends on Channel Usage and Design." Its principal goal is to improve the design and maintenance of navigation channels in order to sustain effective channel navigation and port operations well into the next century. A critical element of this study will be an assessment of how Corps deep-draft channel design and maintenance guidance compares with other domestic and international policies and practices. This assessment will serve to identify areas for further research and for recommending changes in Corps policies and procedures.

Prior to initiating the assessment, the authors were asked to review current practices used domestically and internationally to design and maintain deep-draft navigation channels. Technical publications and the policy guidance of numerous government, professional, and other U.S. and international maritime organizations were identified. A bibliography containing over 200 of the references was gathered and captured in a database that is discussed in Part IV of this report. Bibliographic data contained in this database is reproduced in the Appendix.

Whereas this document, with its annotated bibliography, provides an overview of current deep-draft channel design and maintenance policies world-wide, a follow-on study is underway to compare Corps policy and procedural guidance with the policies and practices of other U.S. and international maritime organizations. A second report that details results of the assessment will be forthcoming.

Part II. OVERVIEW OF CHANNEL DESIGN PLANNING AND RATIONALE

Design Philosophy

Engineer Regulation (ER) 1110-2-1404 prescribes the design procedure and rationale for Corps planning of deep-draft navigation projects. The established design goal is to achieve a waterway that is "safe, efficient, reliable, and economically justified ... with appropriate consideration of environmental and social aspects." Typically, channel design and maintenance involves tradeoffs among these attributes.

For example, whereas an oversized channel can improve the safety and efficiency of operations, it may not be economically justified because of excessive construction and maintenance dredging costs. Contrariwise, a narrow or shallow channel may be economical to construct and maintain, but it will hinder navigation within the waterway and access thereto. Restricted channels may also require special services and facilities such as tug assistance in maneuvering, lighterage operations, or offshore moorings. Regardless of size, navigation channels will necessarily have varying degrees of environmental and social impacts.

Proper channel design can only be achieved with a thorough understanding of the needs of the waterway user, interactions between the user's vessel and the channel environment, and an evaluation of costs and benefits of alternative designs with respect to each attribute. It is the responsibility of the designer to establish channel layout and dimensions that provide an appropriate balance between the competing attributes while accounting for such factors as ship characteristics and behavior, port operations, and environmental conditions. Before discussing the impact of such factors, it is useful to review the characteristic features of most channels.

Channel Features

Figure 2.1 depicts a generic harbor with many of the features and environmental factors that influence channel design. Typical project elements that should be addressed in the design process include:

- Access (or Interior) Channel. The interior channel system that connects the entrance channel to a port or harbor with appropriate ship facilities.

- Anchorage Area. An area adjacent to the access channel that allows a ship to lay at anchor, load and offload cargo, await repairs, etc.

- Entrance Channel. That portion of a navigable channel connecting an open body of water such as an ocean or lake to the mouth of the access channel.

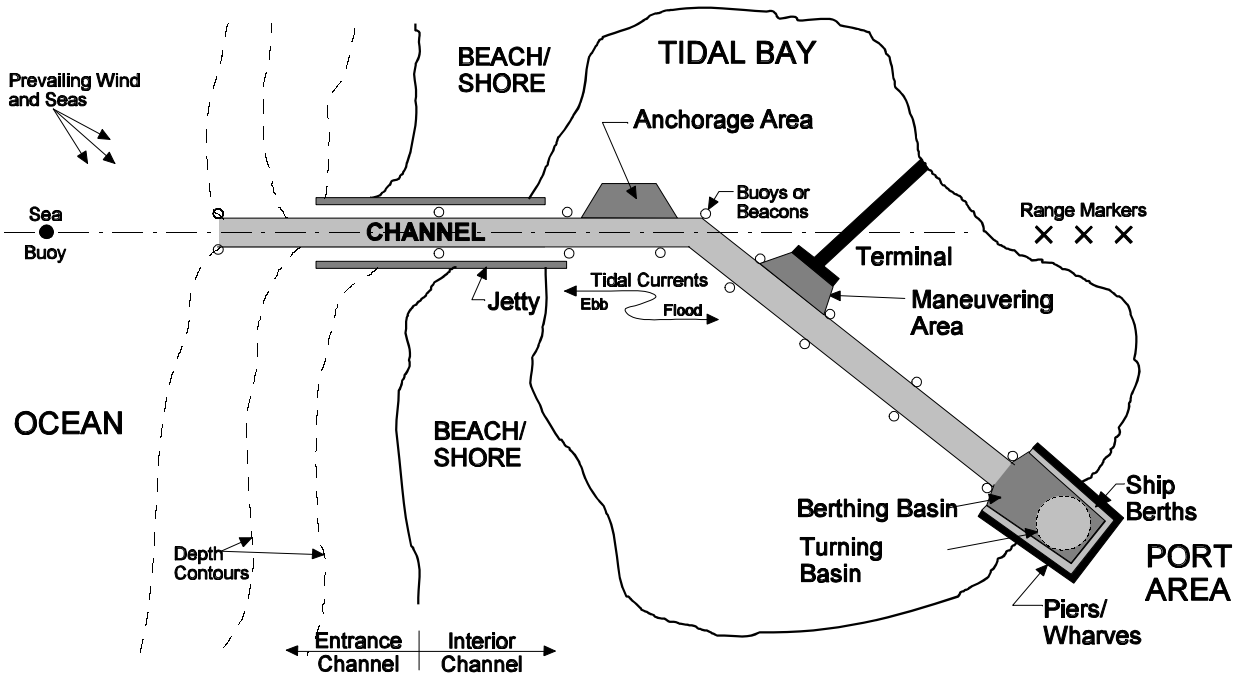

Figure 2.1. Generic Harbor with Typical Project Elements (after [3]).

C Turning Basin. An enlarged area that provides for turning a ship about.

C Other Features. Other features of a navigation channel include breakwaters and jetties that provide shelter and maintain channel alignment; bridge pier and bank protection; maneuvering and passing lanes, ship locks, navigational aids and other systems that provide for safe channel navigation.

Design Parameters

Engineer Manual (EM) 1110-2-1613 provides guidance for preliminary design analysis and for the layout and design of deep-draft navigation projects. Design of navigation channels primarily involves specification of channel geometry, i.e., alignment, depth and width.

C Channel alignment refers to the channel's direction or layout, in plan view. Alignment is somewhat dictated by the natural course of the existing river or estuary so as to minimize initial and maintenance dredging. Adjustments to the natural course may be required to accommodate the users' ships. If so, alignment will depend on the length, beam and maneuverability of the vessels; the location and nature of natural shoals; the positions of existing and proposed structures such as docks and bridge piers, jetties and breakwaters; and, the necessity of providing safe passage. These and other alignment considerations are discussed in Chapter 2 of the manual.

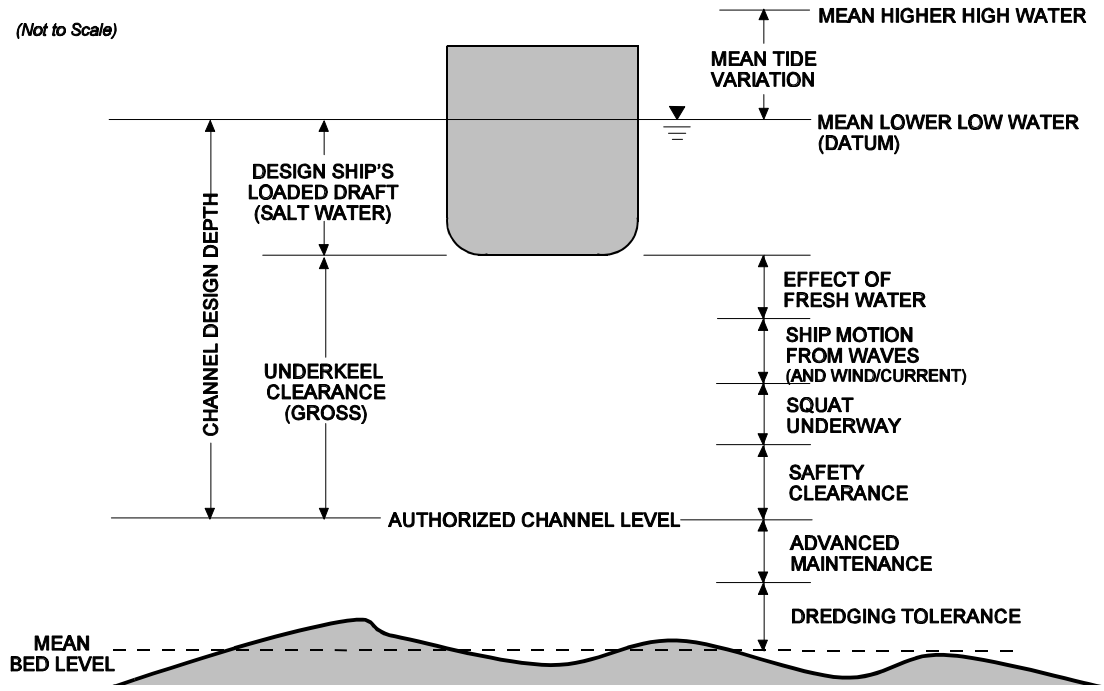

Figure 2.2. Typical Allowances for Channel Depth (from [3]).

C Channel depth is the vertical distance from the water surface to the channel bottom, normally referred to some datum such as mean lower low water (MLLW.) Depth should be adequate to accommodate the draft of the loaded design vessel with allowance for squat, sinkage in fresh water, tidal variations, and the effects of waves, wind, and current. A diagram depicting channel depth based on these allowances is shown in Fig 2.2. Appropriate underkeel clearance must be allowed for safety and efficiency. Economic considerations require an adequate allowance for advanced maintenance and contract dredging tolerances. Other depth considerations include the nature of the channel bottom material and the rate of sedimentation. These and other factors affecting channel depth are discussed in Chapter 6 of the manual.

C Channel width is the horizontal distance between banks on each side of the channel measured at the bottom of the respective side slopes. This distance must be sufficient to accommodate maneuvering lanes for each passing ship, clearance lanes between ships, and bank clearance. The most important factors for determining channel width are length, beam and maneuverability of the vessel; the variability of channel cross-section and alignment; the speed, direction and variability of the current; and the desired traffic pattern (one-way, two-way, or passing). Elements of channel width are depicted in Fig. 2.3. These and other factors affecting choice of channel width are discussed in Chapter 8 of the manual.

Specification of these design parameters is based on the objective to provide for safe, efficient, and reliable navigation while minimizing channel construction and maintenance costs.

Design Considerations

The design process is interactive and involves a number of considerations relating to characteristics of the design vessel(s), site and environmental conditions, and port operations.

- Design Vessel and Vessel Mix. Usually, the largest vessel anticipated to use the waterway is defined as the design vessel. Its speed, maneuvering characteristics, and particularly its size, i.e., length, beam and draft, are major inputs into channel alignment, depth, and width determinations. Two or more distinct design vessels may be specified. For example, one vessel may have a deeper draft, another a wider beam. When navigation traffic into and out of a port is heavy, a design vessel mix will be necessary to establish needs for passing and maneuvering lanes and for turning basins. Designers are encouraged to consider world fleet forecasts when choosing the design vessel and vessel mix.

- Site Factors. Significant site characteristics include the degree of tidal variations such as high and low water levels, water quality with regards to salinity distribution and variability, and geotechnical characteristics and stability of bottom sediments. Stability of channel banks, the rate of sedimentation, and the availability of dredge disposal areas will have a significant impact on economics and, to some extent, the safety, efficiency and reliability of operations. Effects of channel construction and maintenance on the site's ecological balance and other social and cultural impacts must also be considered.

- Environmental Factors. Channel geometries must be chosen to ensure that the design ship is able to make a safe and efficient transit of the channel under each set of likely environmental conditions. Currents, ice, waves and winds affect ship motions and may induce changes in ship draft. Meteorological conditions, such as rain and fog, will affect visibility and possibly compromise operational safety and efficiency. These and other environmental factors will affect ship maneuverability and necessitate either increases in channel width or stricter operational controls.

- Port Factors. Port factors include amount and type of ship traffic, type and availability of navigational aids, and the availability of port pilots and tugs for maneuvering assistance. Information on the type and value of commodities handled by the port are required for project economic studies. Economic benefits will be derived from cost savings associated with transporting these commodities and from an increase in (the value of) goods and services generated by the port. Economic costs include costs of initial construction and those associated with channel maintenance and operations.

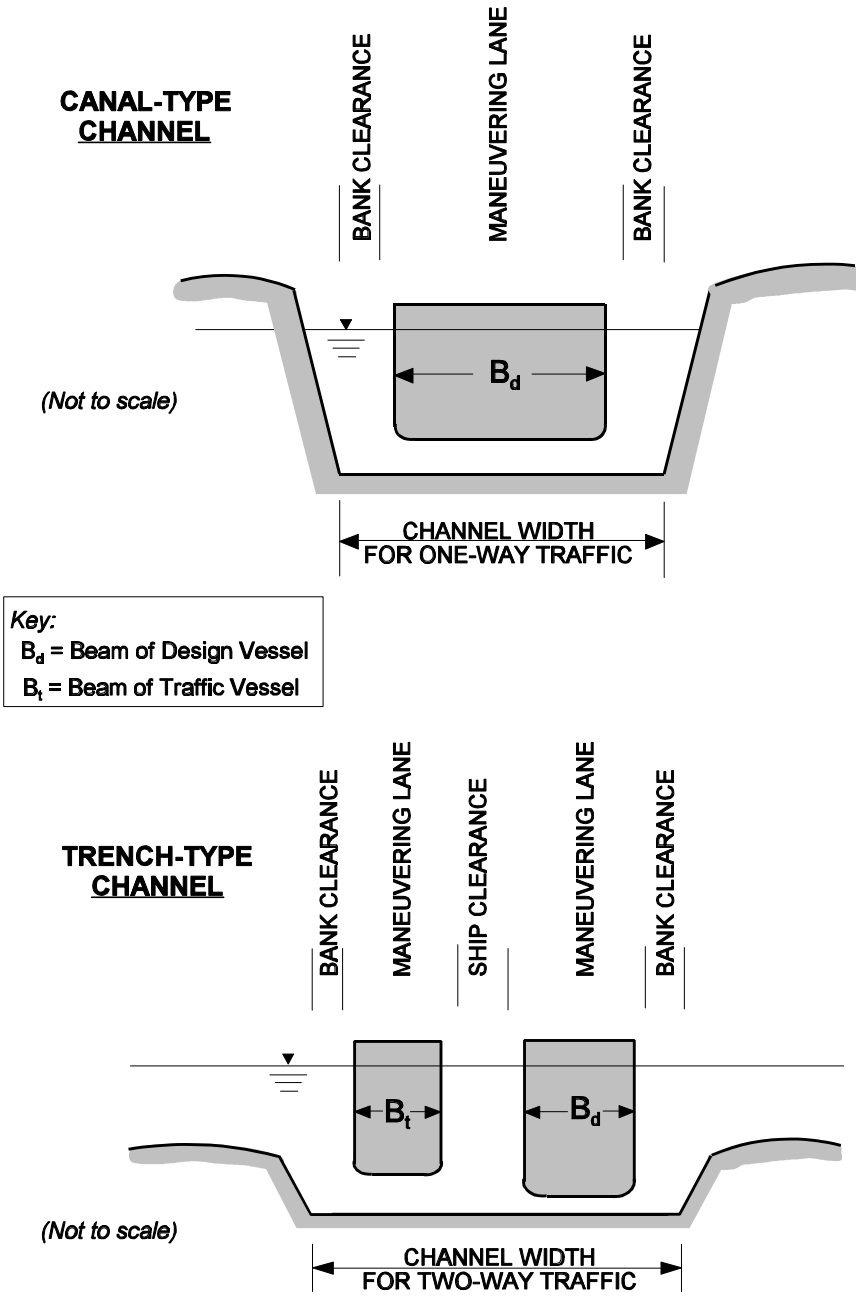

Figure 2.3. Illustrations of Channel Design Width (after [3]).

- Other Factors. Other considerations to be taken into account include local dredging practices, dredge material disposal, and alternatives to dredging such as using offshore terminals and lighterage operations.

The Design Process

Design of a navigation channel may be considered as a two-stage process consisting of concept design and detailed design. During concept design, the designer will establish initial estimates of the proposed channel's physical parameters - alignment, depth and width - both for purposes of alternative evaluation and economic feasibility. Such estimates will usually be based on preliminary information concerning the design ship(s), the site and environment, and knowledge of user needs and operations. Alternatives to wider and deeper channels should be considered. Developing offshore terminals and moorings, employing enhanced navigational aids, implementing stricter operational limits, and providing for passing and maneuvering lanes (in lieu of dual-lane channels) are some options.

Detailed design refines the selected concept-design alternative(s) and finalizes the design parameters. It requires data that is more extensive and reliable than required for concept design. Often, computer models and simulations are used to validate inputs and assumptions. A list of data and model studies required for detailed design of deep-draft navigation channels is provided in Section 2 of EM 1110-2-1613. Channel parameters determined by detailed design may be further validated by marine traffic studies, risk analyses, and benefit-cost analysis. Harbor pilots and shipmasters may also be queried for their opinions of the proposed project design especially with regards to operational safety and efficiency.

A flow chart reflecting the channel design process along with initial inputs is suggested by Figure 2.4. In both the concept and detailed design stages, safety, reliability and efficiency will usually receive primary consideration. Alternatives satisfying acceptable levels of these attributes will then be evaluated on the basis of life-cycle cost effectiveness. This evaluation will include appropriate account of anticipated maintenance dredging activities and also environmental and social impacts. Normally, the channel layout resulting in the greater net benefits (over costs) is the preferred alternative.

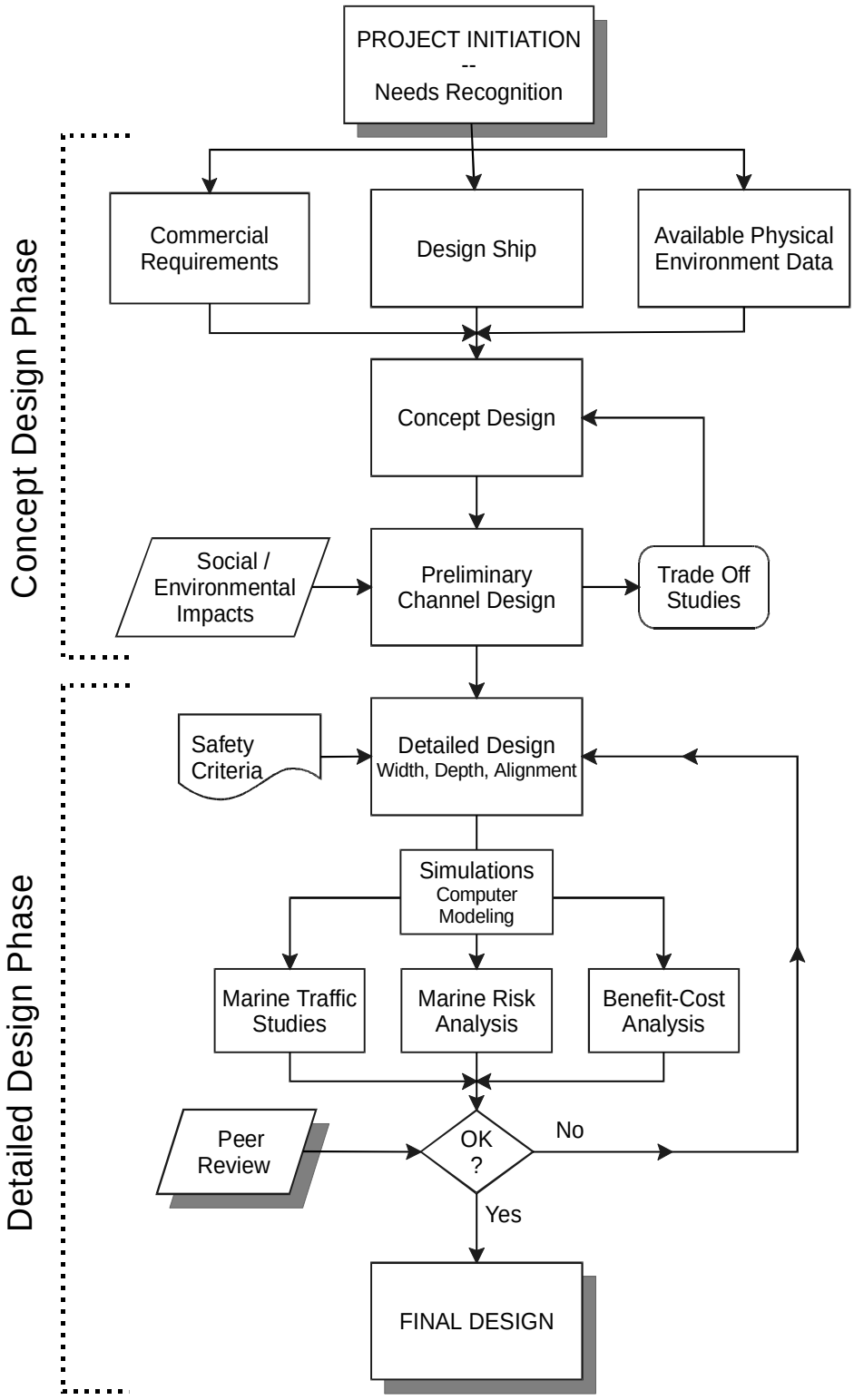

Figure 2.4. The Channel Design Process (after [4]).

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Part III. BIBLIOGRAPHIC DATABASE

Database Application Program

Prior to initiating the comparison study of Corps and other organizations' guidance, it was necessary to perform an intensive literature search to identify relevant codes, criteria, specifications and other technical information pertaining to deep-draft navigation channel design. To date, more than 300 books, papers, reports and other forms of documentation pertaining to the design process have been identified and reviewed. Given the large volume of information, the authors decided that it was both necessary and convenient to establish a bibliographic database to categorize these references with respect to content and relevancy to the IWR study.

The database program chosen for the bibliographic summary is Microsoft Access 97 for Windows 95/98 and Windows NT operating systems. Access 97 is among the suite of desktop applications in Microsoft Office 97, Professional Version. It was chosen both for its technical features and its wide availability in both the government and business communities.

Among its technical features are a convenient means of entering and updating information in the database and the availability of various sorting, filtering and reporting methods. These and other features will be discussed briefly in the following section.

Access database files can be readily saved in HTML (hypertext markup language) format for export/import across an intranet or the World Wide Web (WWW). Once there, multiple users at different locations can query, update and add additional information.

Description of Database

Each bibliographic record included in this database is stored in a data table. A segment of the table with a subset of records is shown in Figure 3.1. For purposes of this study, the table consists of two sets of fields. *Bibliographic fields* are used for documenting normal bibliography data such as author, document title, publisher and publication date. This set of fields will appeal to a wide audience. The second set of *Database Management fields* facilitates database maintenance and document control and aids in the production of this and subsequent reports. A brief summary of the contents within each field set follows.

<	Bibliographic fields	Descriptor
	Entry Number	A unique number associated with each bibliographic record.

Author	Name(s) of the authors. The preferred format is: Last name, first and middle initials of the 1st author; first and middle initials and last name of the 2nd author; etc.
Paper/Report Title	Title of a paper or report; the title will usually appear in quotes.
Text Title	Title of the book, journal, etc.
2nd Title	Additional title information such as volume number, edition, etc.
Publisher	Publisher and location thereof.
Date Pubd	Date of publication, e.g., DD/MM/YY, as appropriate.
Year Pubd	Year of publication.
Pgs/Pg Nos	Total number of pages of a text reference; or, page numbers of a paper or article.
Abstract	Summary of the document's contents as it pertains to the IWR study.

< Database Management fields:

Ver	Initial(s) of principal investigator who last verified/modified the bibliographic information.
File Under	Category under which copies of this document are filed.
Location 1	Principal location(s) of the document.
Location 2	Alternate or permanent location of document, e.g., library.
Web Location	WWW hyperlink address, when appropriate.
Comments	Supplemental comments pertaining to the availability or significance of the document.
Safety Performance Review	This numeric field reflects the expected importance/usefulness of the document to a particular phase of the IWR Study. (1Ya Critical Document usually covering multiple aspects of the phase; 2Ya Possibly Critical Document covering at least a single aspect or issue of the phase; 3Ya Non-Critical Document that deals with peripheral issues. Absence of a numeric indicates that either the document has

no apparent relevance to this phase of the study or, possibly, that its significance has yet to be determined.)

Channel Design Assessment . . . *see description for "Safety Performance Review"*

Channel Maintenance & Operations Assessment . . . *see description for "Safety Performance Review"*

Shipping Trends Analysis . . . *see description for "Safety Performance Review"*

In addition, there are 45 distinct *Keyword fields* to facilitate identification of references pertaining to specific phases of the IWR study or factors relating thereto. Although the authors of the database have established these fields to support subsequent research, it is planned that appropriate keywords will subsequently be grouped in a single field to aid the general database user.

Keyword Locators

The subsequent study that will compare Corps policy and guidance with that of other domestic and international organizations will necessarily address many aspects of channel maintenance and design. To ease retrieval of common data, a select list of keywords (or key phrases) was identified, and each keyword was stored in a data table that, in turn, was linked to the bibliographic table and bibliographic form of the database. The selected keywords were grouped within seven categories relating primarily to channel design and three categories relating to channel maintenance and operations. Two keyword categories were also identified for both the Safety Performance Review and the Shipping Trends Analysis.

The seven keyword categories concerning channel design are Codes/Guidance, Design Methods, Design Parameters, Design Ship, Environmental Factors, Port Factors, and Site Histories. Categories pertaining primarily to channel maintenance and operations are Criteria/Rationale, Decision Support Systems, and Dredging. Special Interest Channels/Projects and Channel Design/Usage Analysis were chosen as primary categories for the Safety Performance Review, and Current/Future Navigation Trends and Channel Design/Safety Impacts are counterparts for the Shipping Trends Analysis. Keywords relating to each category are reflected in Figure 3.3. The figure illustrates an Access Database form for direct entry of keywords associated with each individual record. As with the bibliographic form, this keyword form is easily modified to add or delete keywords whenever appropriate.

Database Maintenance

Authorized users can enter new or revised information directly in the database table or, more conveniently, by "form." Figure 3.2 illustrates a bibliography form created for this database. It

shows bibliographic and data management information for one of more than 200 records identified in this study. The advantage of the form is that is displays all fields of a single record. In addition, buttons are available for moving from one record to another and for entering keywords. The user may type (or paste) information directly in the appropriate fields or make use of several drop-down menus for recording frequently cited entries. For example, "Department of the Army, Washington, D.C." is among the menu selections in the "Publisher" field.

This database form also supports data queries as will be explained below. The form itself is easily modified to add or delete fields and menus, as necessary.

Use of Database

This database is intended to provide easy biographical access to the references reviewed in this study.

Access 97 supports sorting of data in ascending (or descending) alpha-numeric order in one or more fields. Records satisfying a specified search criteria can also be isolated and sorted by "filtering." There are a variety of filtering methods including:

- Filtering for Input - In response to typed input, Access isolates all records with the specified text in a chosen field; e.g., all records with the term underkeel clearance in the "Abstract" field.

- Filtering by Selection - In response to highlighted text in a specific record, Access isolates all records with the specified text in the same field; e.g., all records with the highlighted text McCartney in the "Author" field.

- Filtering by Form - In a form, Access isolates all records meeting certain criteria in one or more fields; e.g., all records by McCartney (in the "Author" field) published since 1993 in the "Year Pubd" field.

An even more powerful sorting/filtering feature of Access 97 is the "Query." Query is a formal way to isolate and sort records by criteria in one or more fields and, then, to have certain fields limited and ordered for monitor display and report generation. The bibliography that appears in the Appendix is the result of a Query that was limited to bibliographic fields. A near-unlimited variety of individual report formats is possible for display of specific bibliographic and database management information.

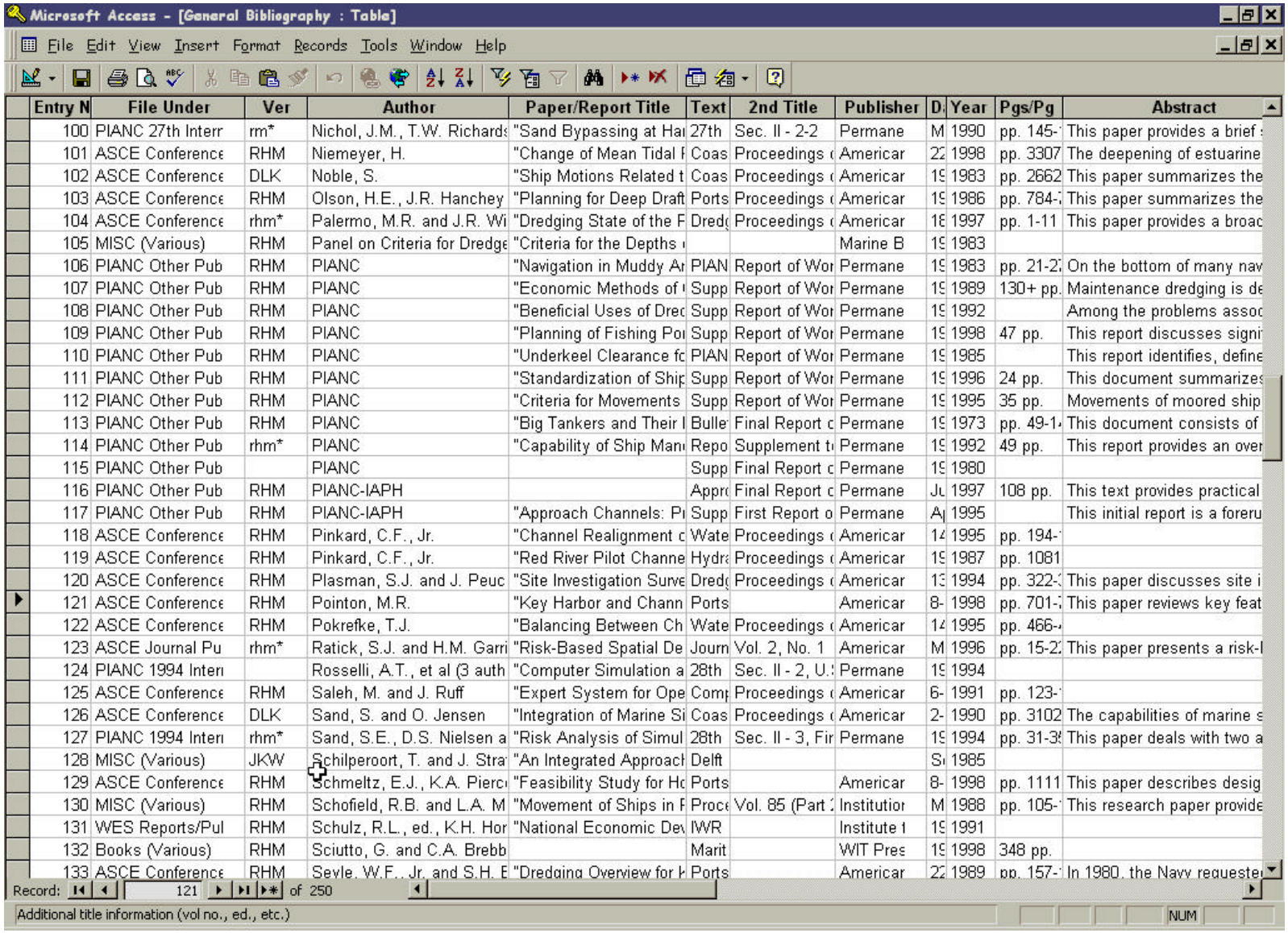

Figure 3.1. Partial View of Access Database Table for Bibliographic Information.

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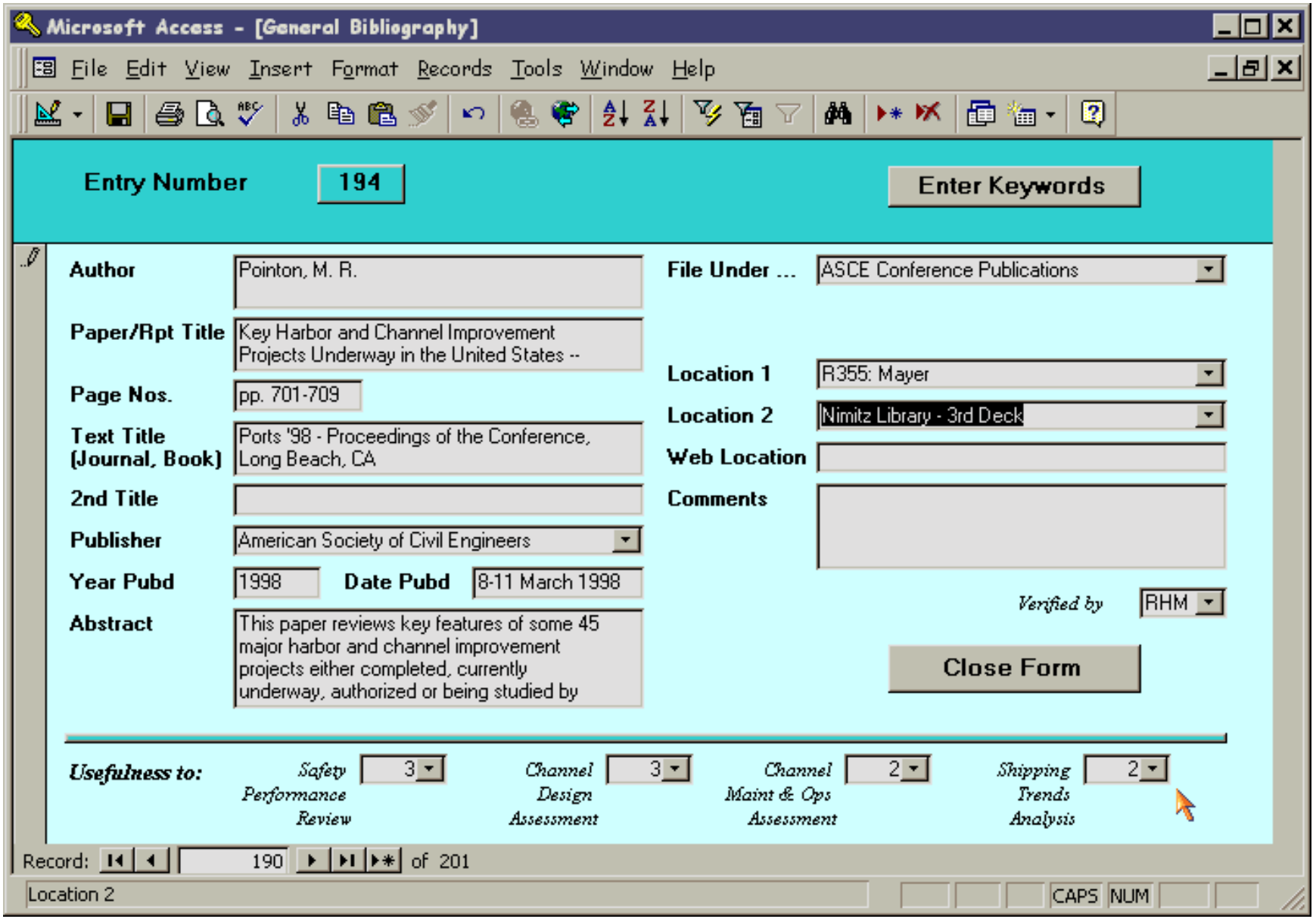

Figure 3.2. View of Access Database Form for Entering Bibliographic Information.

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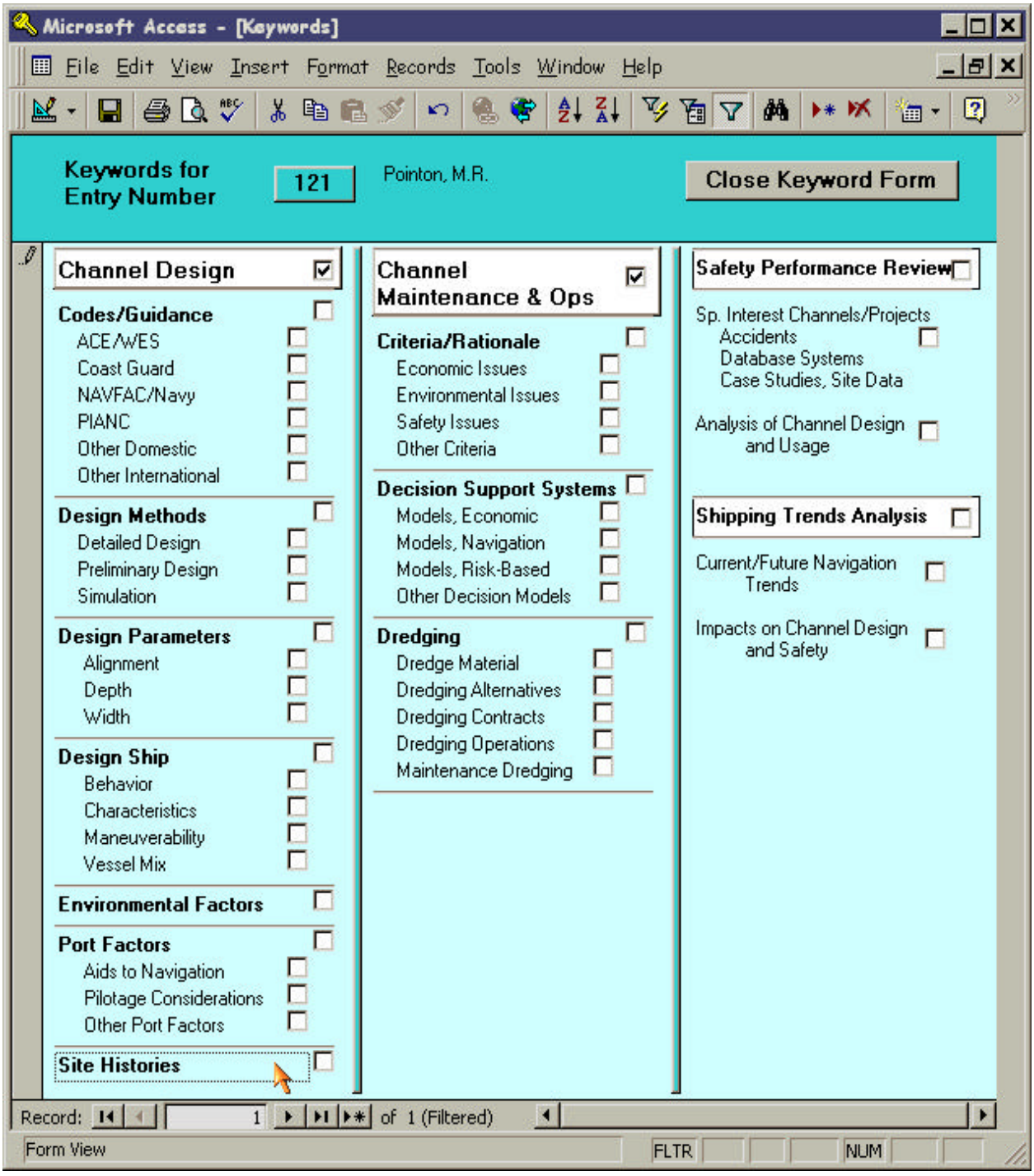

Figure 3.3. View of Access Database Form for Entering Keywords.

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Part IV. SUMMARY

This report provides a brief overview of policies and practices established by the U.S. Army Corps of Engineers for the design and maintenance of deep-draft navigation channels. In sum, the established design goal is to achieve a waterway that is safe, efficient, reliable, and economical with appropriate consideration of environmental and social aspects. Navigation channel design is a complex process that requires the designer to consider tradeoffs among these attributes while integrating various factors relating to the site, its environment, the port and the design ship. Also, design procedures must necessarily adapt to changes in the shipping industry as ships of increasing size and speed are developed.

To better prepare for these changes, the Corps' Institute for Water Resources initiated its study entitled "Impacts of Navigation Trends on Channel Usage and Design." The authors, in turn, accomplished a literature review of navigation channel design and maintenance policies and practices of domestic and international maritime organizations. This review resulted in a bibliography containing more than 200 references compiled in a desktop database. The principal bibliographic information is reproduced in the Appendix. The intent of this compilation is to facilitate comparison of Corps policy and guidance with that of other organizations. A follow-on study is underway to detail this comparison and, if necessary, to recommend changes in current policy and identify areas for further research. Copies of the complete Access Database file (1650 MB) are available from the Institute and the authors.

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2. U.S. Army Corps of Engineers, "Hydraulic Design of Deep-Draft Navigation Projects," Engineer Regulation (ER) 1110-2-1404, Department of the Army, Washington, D. C., 31 Jan 1996.

3. U.S. Army Corps of Engineers, "Hydraulic Design Guidance for Deep-Draft Navigation Projects," Engineer Manual (EM) 1110-2-1613, Department of the Army, Washington, D. C., 31 Aug 1995.

4. PIANC, "Approach Channels: A Guide for Design," Report of Working Group II-30, Permanent International Association of Navigation Congresses, Brussels, June 1997.

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APPENDIX. ANNOTATED BIBLIOGRAPHY

The following pages reflect the bibliographic content of the database prepared for the IWR study, "Impacts of Navigation Trends on Channel Usage and Design.". The bibliographic entries have been ordered by author and are presented in the following format:

> Author(s), **"Paper or Report Title,"** ***Text or Journal Title, 2nd Title,*** Publisher, Date Published, total number of pages or page numbers, web site address (when appropriate)**.**
>
> *Abstract:*
>
> (Abstract, if available. [source of abstract])
>
> *Keywords:* (List of Keywords, if available.)
>
> *Channel Design: .....# Safety Performance Review: ..... #*
> *Channel Maintenance and Operations .....# Shipping Trends Analysis: ..... #*
>
> *(Database Entry Number #)*

Abbreviations used for "[source of abstract]" include the following:

oa:	original abstract	dk:	study author (dave kriebel)
oa-m:	original abstract, modified or abbreviated		
od:	original document	jw:	study author (jennifer waters)
ws:	web site	rm:	study author (robert mayer)

It should be noted that not all database information is shown. Additional information includes document location and study-authors' notes pertinent to the preparation of other reports associated with the study. Also, the database should be considered a working document. Throughout this IWR study, incomplete bibliographic data will be updated as it discovered and additional bibliographic entries will be added, as appropriate.

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